

**RESIN COMPOSITIONS AND METHODS OF USING SUCH RESIN COMPOSITIONS
IN SUBTERRANEAN APPLICATIONS**

BACKGROUND

[0001] The present invention relates to resin compositions and methods of using such compositions in subterranean formations. More particularly, the present invention relates to curable, permeable resin compositions and methods of using such compositions, for example, to control particulate migration.

[0002] Hydrocarbon wells are often located in subterranean zones that contain unconsolidated particulates that may migrate out of the subterranean formation with the oil, gas, water, and/or other fluids produced by the wells. The presence of particulates, such as formation sand, in produced fluids is undesirable in that the particulates may abrade pumping and other producing equipment and reduce the fluid production capabilities of the producing zones. Unconsolidated subterranean zones include those that contain loose particulates, those wherein the bonded particulates have insufficient bond strength to withstand the forces produced by the production of fluids through the zones.

[0003] One method of controlling particulates in unconsolidated formations involves placing a filtration bed containing gravel near the well bore in order to present a physical barrier to the transport of unconsolidated formation fines with the production of hydrocarbons. Typically, such so-called "gravel packing operations" involve the pumping and placement of a quantity of a desired particulate into the unconsolidated formation in an area adjacent to a well bore. Such packs may be time consuming and expensive to install.

[0004] Another method used to control particulates in unconsolidated formations involves consolidating unconsolidated subterranean producing zones by applying a resin followed by a spacer fluid and then a catalyst. Such techniques, however, may be problematic when, for example, an insufficient amount of spacer fluid is used between the application of the resin and the application of the external catalyst. The resin may come into contact with the external catalyst in the well bore itself rather than in the unconsolidated subterranean producing zone, which may result in rapid polymerization, potentially damaging the formation by plugging the pore channels, halting pumping when the well bore is plugged with solid material, or

resulting in a down hole explosion as a result of the exothermic heat generated by the polymerization. Also, using these conventional processes to treat long intervals of unconsolidated regions is not practical due to the difficulty in determining if the entire interval has been successfully treated with both the resin and the external catalyst.

SUMMARY OF THE INVENTION

[0005] The present invention relates to resin compositions and methods of using such compositions in subterranean formations. More particularly, the present invention relates to curable, permeable resin compositions and methods of using such compositions, for example, to control particulate migration.

[0006] One embodiment of the present invention provides a method of creating a resin mass comprising the steps of combining a resin, a hardening agent, a hydrocarbon diluent, a silane coupling agent, a foaming agent, a compressible gas, and a degradable material to form a resin composition; placing the resin composition in a subterranean formation; and, allowing the resin to substantially cure and the degradable material to substantially degrade so as to form a permeable, hardened resin mass.

[0007] Another embodiment of the present invention provides a method of controlling the migration of particulates in a subterranean formation comprising the steps of isolating a zone in a subterranean formation; providing a resin composition comprising a resin, a hardening agent, a hydrocarbon diluent, a silane coupling agent, a foaming agent, a compressible gas, and a degradable material; placing the resin composition in at least a portion of the zone; and, allowing the resin to substantially cure and the degradable material to substantially degrade so as to form a permeable, hardened resin mass.

[0008] Another embodiment of the present invention provides a method of at least partially maintaining the integrity of a subterranean fracture comprising the steps of providing a resin composition comprising resin, a hardening agent, a hydrocarbon diluent, a silane coupling agent, a foaming agent, a compressible gas, and a degradable material; placing the resin composition into at least one fracture in a subterranean formation; and, allowing the resin to substantially cure and the degradable material to substantially degrade so as to form a permeable, hardened resin mass.

[0009] Another embodiment of the present invention provides a resin composition useful in subterranean applications comprising a resin, a hardening agent, a hydrocarbon diluent, a silane coupling agent, a foaming agent, a compressible gas, and a degradable material.

[0010] The features and advantages of the present invention will be readily apparent to those skilled in the art upon a reading of the description of the preferred embodiments that follows.

DESCRIPTION OF PREFERRED EMBODIMENTS

[0011] The present invention relates to resin compositions and methods of using such compositions in subterranean formations. More particularly, the present invention relates to curable, permeable resin compositions and methods of using such compositions, for example, to control particulate migration.

[0012] The resin compositions of the present invention comprise an epoxy resin; a hardening agent; a hydrocarbon diluent; a silane coupling agent; a foaming agent; a compressible gas; and, a degradable material. The resin compositions of the present invention may further comprise an optional filler material. Such resin compositions are capable of being placed in a zone of a subterranean formation, such as a fracture or a well bore, so as to form hardened, permeable masses capable of controlling particulate migration while not negatively impacting the production of desirable fluids. When a resin composition of the present invention is placed in or neighboring the desired zone, the resin hardens and the void spaces left by the compressible gas are further augmented when the degradable material degrades and creates additional voids within the hardened resin mass. These voids enhance the permeability of the hardened resin, which results, *inter alia*, in enhanced mass conductivity that may enhance well productivity. The resin compositions of the present invention provide the ability to form an *in-situ* porous medium capable of controlling formation fines and sands while allowing hydrocarbon production.

[0013] Resins suitable for use in the present invention are those resins that are capable of forming a hardened, consolidated mass. Suitable resins include, but are not limited to phenolic resins, furan/furfuryl alcohol resins, phenolic/latex resins, phenol formaldehyde resins, polyester resins and hybrids and copolymers thereof, polyurethane resins and hybrids and copolymers thereof, acrylate resins, and mixtures thereof. Preferred types of resin are epoxy resin systems. Epoxy resin systems generally contain an internal catalyst or activator so that when pumped down hole, they may be cured using only time and temperature where desired. The furan resin systems generally require a time-delayed catalyst or an external catalyst to help activate the polymerization of the resins if the cure temperature is low (*i.e.*, less than 250 °F), but will cure under the effect of time and temperature if the formation temperature is above about 250°F, preferably above about 300°F. It is within the ability of one skilled in the art, with the benefit of this disclosure, to select a suitable resin for use in embodiments of the present invention.

[0014] The resin compositions of the present invention further comprise a hardening agent. Suitable hardening agents are those materials capable of aiding the selected resin to form a consolidated mass. Examples of the hardening agents that can be used include, but are not limited to, amines, aromatic amines, polyamines, aliphatic amines, cyclo-aliphatic amines, amides, polyamides, 2-ethyl-4-methyl imidazole, 1,1,3-trichlorotrifluoroacetone, and combinations thereof. Selection of a suitable hardening agent depends, in part, on the resin chosen and the temperature of the formation in which the hardening agent will be used. By way of example and not of limitation, in subterranean formations having a temperature from about 60°F to about 250°F, amines and cyclo-aliphatic amines such as piperidine, triethylamine, N,N-dimethylaminopyridine, benzyldimethylamine, tris(dimethylaminomethyl) phenol, and 2-(N₂N-dimethylaminomethyl)phenol are preferred with N,N-dimethylaminopyridine most preferred. In subterranean formations having higher temperatures, 4,4'-diaminodiphenyl sulfone may be a suitable hardening agent. In some embodiments of the present invention, the hardening agent used may be included in the resin composition in the range of from about 40% to about 60% by weight of the resin in the resin composition.

[0015] The resin compositions of the present invention further comprise a hydrocarbon diluent containing one or more aromatic hydrocarbons. Suitable hydrocarbon diluents, *inter alia*, act to dilute the viscosity of the resin and such diluents are often chosen based on availability and cost concerns. Examples of suitable aromatic hydrocarbon diluents include, but are not limited to, toluene, ethylbenzene, n-propylbenzene; isopropylbenzene, n-butylbenzene, isobutylbenzene, cyclohexylbenzene, n-hexylbenzene, xylene, diethylbenzene, 2-chloro-p-xylene, diisopropylbenzene, 2-nitro-p-xylene, cymene, durene, isodurene, trimethylbenzene, triethylbenzene, dibutylbenzene, penta-methylbenzene, 1-pentyl-3-ethylbenzene, p-pentyltoluene, 1-hexyl-3-isobutylbenzene, m-hexyltoluene, 1-heptyl-3-isopropylbenzene, p-heptyltoluene, 1-heptyl-3-ethylbenzene, 1-octyl-3-butylbenzene, 1-octyl-3-propylbenzene, p-octyltoluene, 1-nonyl-3-ethylbenzene, p-nonyltoluene, 1-dodecyl-3-ethylbenzene, p-isodecyltoluene, 1-decyl-3-isotridecylbenzene, and mixtures thereof. In some embodiments of the present invention, the hydrocarbon diluent is included in the resin composition in the range of from about 20% to about 60% by weight of the resin in the resin composition. It is within the ability of one skilled in the art, with the benefit of this disclosure, to select a suitable diluent and a suitable percentage of diluent.

[0016] The resin compositions of the present invention further comprise a silane coupling agent that acts to help the resin bond to the degradable material (and filler, where used) in the resin composition. Examples of silane coupling agents that can be used in the resin compositions of the present invention include, but are not limited to, N-2-(aminoethyl)-3-aminopropyltrimethoxysilane, 3-glycidoxypentyltrimethoxysilane, n-beta-(aminoethyl)-gamma-aminopropyl trimethoxysilane, and combinations thereof. The silane coupling agent chosen is included in the liquid hardening agent component in an amount capable of sufficiently bonding the resin to a particulate. In some embodiments of the present invention, the silane coupling agent used is included in the resin composition in the range of from about 0.01% to about 5% by weight of the resin in the resin composition.

[0017] The resin compositions of the present invention further comprise a foaming agent that comprises a fluorocarbon surfactant. Traditional foaming agents are incompatible with the resin component of the resin compositions of the present invention. However, it has been found that foaming agents comprising a fluorocarbon surfactant are suitable for forming a stable foam in the resin compositions of the present invention. Examples of suitable foaming agents comprising fluorocarbon surfactants include, but are not limited to, fluorinated alkyl alkoxylates, fluorinated alkyl esters, fluorinated aliphatic polymeric esters, and combinations thereof. Examples of suitable, commercially available foaming agents comprising a fluorocarbon surfactant include those sold by 3M Company of St. Paul, MN under the trade names "FC-730TM," "FC-4430TM," and "FC-4432TM." In some embodiments of the present invention, the foaming agent is included in the resin composition in the range of from about 0.01% to about 5% by weight of the resin in the resin composition.

[0018] The resin compositions of the present invention further comprise a compressible gas. Any compressible gas that does not adversely react with or affect the other components of the resin composition may be used in accordance with the present invention. Suitable compressible gases include air, nitrogen, and combinations thereof. Carbon dioxide may be contraindicated based on the resin type selected. For example, where an epoxy resin is used, the acidity of a carbon dioxide compressible gas may prevent adequate curing of the resin. Similarly, where a furan resin is chosen, the acidity of the carbon dioxide may cause premature curing and potential safety concerns. One of ordinary skill in the art, with the benefit of this disclosure, will recognize situations wherein carbon dioxide is contraindicated. In some

embodiments of the present invention, the compressible gas is included in the resin composition in an amount sufficient to produce a final resin composition density from about 6 to about 12 pounds per gallon (including filler material).

[0019] The resin compositions of the present invention further comprise a degradable material capable of undergoing an irreversible degradation down hole. In some embodiments of the present invention, the degradable material is included in the resin composition in the range of from about 1% to about 60% by weight of the resin in the resin composition. The amount of degradable material used should not be such that, when degraded, an undesirably high percentage of voids are present in the resin mass that potentially could make the resin mass too weak to maintain its character or allow the resin mass to crumble or degrade. One of ordinary skill in the art, with the benefit of this disclosure, will recognize an optimum concentration and shape of a degradable material that provides desirable values in terms of enhanced conductivity or permeability without undermining the stability of the resin mass itself.

[0020] The term “irreversible” as used herein means that the degradable material once degraded down hole, it should not recrystallize or reconsolidate while down hole, *e.g.*, the degradable material should degrade *in situ* but should not recrystallize or reconsolidate *in situ*. The terms “degradation” or “degradable” refer to both the two relatively extreme cases of hydrolytic degradation that the degradable material may undergo, *i.e.*, heterogeneous (or bulk erosion) and homogeneous (or surface erosion), and any stage of degradation in between these two. This degradation can be a result of, *inter alia*, a chemical, thermal, radiation induced reaction.

[0021] Examples of degradable materials that may be used in conjunction with the present invention include but are not limited to materials that undergo hydrolysis in the presence of water (such as degradable polymers and dehydrated salts) and materials that degrade when subjected to the subterranean temperatures where the resin is being used (such as sodium acetate trihydrate). One of ordinary skill in the art with the benefit of this disclosure will be able to determine the appropriate degradable material to achieve the desired degradation time, result in the desired degradation by-products, and the like.

[0022] Suitable examples of degradable polymers that may be used in accordance with the present invention, include, but are not limited to, those described in the publication of Advances in Polymer Science, Vol. 157 entitled “Degradable Aliphatic Polyesters” edited by A.-

C. Albertsson. Specific examples of suitable polymers include polysaccharides; chitins; chitosans; proteins; aliphatic polyesters; poly(lactides); poly(glycolides); poly(ϵ -caprolactones); poly(hydroxybutyrates); poly(anhydrides); aliphatic polycarbonates; poly(orthoesters); poly(amino acids); poly(ethylene oxides); polyphosphazenes; polyvinyl alcohols; poly ethylene oxides; poly(adipic anhydrides), poly(suberic anhydrides), poly(sebacic anhydrides), poly(dodecanedioic anhydrides), poly(maleic anhydrides), poly(benzoic anhydrides); and combinations thereof. Poly(lactides) are preferred degradable polymers for the compositions and methods of the present invention.

[0023] Suitable examples of dehydrated salts that may be used in conjunction with the present invention include, but are not limited to, particulate solid anhydrous borate materials. Specific examples of particulate solid anhydrous borate materials that may be used include but are not limited to anhydrous sodium tetraborate (also known as anhydrous borax), and anhydrous boric acid. Such anhydrous borate materials are only slightly soluble in water. However, with time and heat in a subterranean environment, the anhydrous borate materials react with the surrounding aqueous fluid and are hydrated. The resulting hydrated borate materials are highly soluble in water as compared to anhydrous borate materials and as a result degrade in the aqueous fluid. In some instances, the total time required for the anhydrous borate materials to degrade in an aqueous fluid is in the range of from about 8 hours to about 72 hours depending upon the temperature of the subterranean zone in which they are placed.

[0024] Blends of degradable materials also are suitable for use in the present invention. One example of a suitable blend of materials is a mixture of poly(lactic acid) and sodium borate where the mixing of an acid and base could result in a neutral solution where this is desirable. Another example would include a blend of poly(lactic acid) and boric oxide.

[0025] In choosing the appropriate degradable material, one should consider the degradation products that will result. These degradation products should not adversely affect other operations or components. The choice of degradable material also can depend, at least in part, on the conditions of the well, *e.g.*, well bore temperature. For instance, lactides have been found to be suitable for lower temperature wells, including those within the range of 60°F to 150°F, and poly(lactides) have been found to be suitable for well bore temperatures above this range. Also, poly(lactic acid) may be suitable for higher temperature wells. Some stereoisomers

of poly(lactide) or mixtures of such stereoisomers may be suitable for even higher temperature applications. Dehydrated salts may also be suitable for higher temperature wells.

[0026] A preferable result is achieved if the degradable material degrades slowly over time as opposed to instantaneously. Even more preferable results have been obtained when the degradable material does not begin to degrade until after the resin composition has substantially cured. The slow degradation of the degradable material, *inter alia*, helps to maintain the stability of the cured resin mass. In preferred embodiments, the degradable material does not degrade from or out of the resin mass until the resin is at least about 90% cured.

[0027] The specific features of the degradable material may be chosen or modified to provide the consolidated resin mass with optimum conductivity while maintaining its desirable filtering capability. The physical shape of the degradable material should be chosen so as to enhance the desired shape and relative composition of the resultant voids within the resin mass so as to provide the cured resin mass with optimum permeability and conductivity characteristics. For example, a rod-like particle shape may be suitable in applications wherein channel-like voids in the final resin mass are desired. One of ordinary skill in the art, with the benefit of this disclosure, will recognize the specific degradable material and the preferred size and shape for a given application. Preferably, the degradable material is substantially evenly dispersed throughout the resin composition.

[0028] The resin compositions of the present invention optionally may comprise a particulate filler material. The filler material may be used as a low cost additive to increase the total volume of the resin composition. The filler material may be chosen to add compressive strength, to achieve a desired density, to provide a cost savings, or all of the above. Fillers chosen for strength may be particularly useful in situations in which the resin compositions of the present invention are used to fill subterranean fractures and must be able to withstand closure stress once the formation is placed on production. Any particulate suitable for use in subterranean applications is suitable for use as the filler in the compositions and methods of the present invention. For instance, sand, nut hulls, bauxite, ceramics, polymeric materials, fly ash, bottom ash, a combination thereof, or the like are suitable. Suitable sizes range from 6 to 325 U.S. mesh. In some embodiments of the present invention, the filler material may be included in the resin composition in the range of from about 1% to about 100% by weight of the other components in the resin composition. The filler material is preferably included in the resin

composition in the range of from about 60% to about 80% by weight of the other components in the resin composition. When used, in preferred embodiments, the filler material should be substantially evenly dispersed throughout the resin composition before it is placed into the subterranean formation.

[0029] Some embodiments of the present invention provide methods of creating resin compositions comprising the step of combining a resin, a hardening agent, a hydrocarbon diluent, a silane coupling agent, a foaming agent, a compressible gas, and a degradable material to form a substantially uniform mixture.

[0030] Other embodiments of the present invention provide methods of controlling the migration of particulates in a subterranean formation comprising the steps of isolating an interval in a subterranean formation; providing a resin composition comprising a resin, a hardening agent, a hydrocarbon diluent, a silane coupling agent, a foaming agent, a compressible gas, and a degradable material; placing the resin composition in or neighboring to at least a portion of the isolated interval; and, allowing the resin to substantially cure and the degradable material to substantially degrade so as to form a permeable, hardened resin mass.

[0031] Still other embodiments of the present invention provide methods of at least partially maintaining the integrity of a subterranean fracture comprising the steps of providing a resin composition comprising resin, a hardening agent, a hydrocarbon diluent, a silane coupling agent, a foaming agent, a compressible gas, and a degradable material; placing the resin composition into at least one fracture in a subterranean formation; and, allowing the resin to substantially cure and the degradable material to substantially degrade so as to form a permeable, hardened resin mass.

[0032] Thus, the present invention is well adapted to carry out the objects and attain the ends and advantages mentioned as well as those that are inherent therein. While numerous changes may be made by those skilled in the art, such changes are encompassed within the spirit and scope of this invention as defined by the appended claims.